"Volage" made it possible to extend the original programme so as to include records of all the attendant phenomena.

The paper gives an account of the preparation of instruments and huts, and of the organisation of the "Volage" observers into parties for different branches of the work. For the benefit of others who may be similarly circumstanced on future occasions, full particulars of these working parties and the instructions issued to them are included in the paper, and the arrangements for working the larger instruments are also described.

On the morning of the eclipse the sky was almost entirely overcast, and the sun was quite invisible during totality.

No photographs were obtained, but some observations of temperature, colours of the landscape, and the general phenomena of totality were secured. As shown by two thermometers screened from the direct rays of the sun, the temperature fell 0·9° F. from first contact to totality, and rose the same amount between totality and last contact. A fully exposed thermometer at another place indicated a fall of 6·5° F., and a subsequent rise of 1·5° F. during the same intervals.

"On the Classification of Stars of the δ Cephei Class." By J. Norman Lockyer, C.B., F.R.S. Received May 17,—Read June 17, 1897.

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Introduction.

The spectrum of δ Cephei is one of a group with special characteristics. While containing a great number of fine metallic lines, giving it more or less the same general appearance as the solar spectrum, it shows many lines which are either faint in the solar spectrum or are altogether absent. In a former paper* I showed that the spectrum is practically identical with that of γ Cygni, which my previous work had indicated to be a star of increasing temperature.†

The chief argument which I had employed in favour of placing γ Cygni on the ascending side of the temperature curve was based on the presence of certain special lines, which occur with increased importance, in the spectrum of α Cygni, which differs very widely from the solar spectrum, and has a close relationship to the Orion stars.

Further, the association of a special kind of variability with some of the stars having a spectrum of this type seemed to strengthen the view that the constitution of such stars must be vastly different from that of the sun. Dr. Vogel, however, has classified two stars of the same group as δ Cephei, namely, η Aquilæ and 10 Sagittæ,

* 'Roy. Soc. Proc.,' vol. 59, p. 103.

† 'Phil. Trans.,' A, vol. 184, p. 718.

with the sun in his Class IIa, and more recently Dr. Scheiner has placed another star of the group, α Persei, between α Cygni and the sun. It is right to add that Drs. Vogel and Scheiner differ very considerably as to the classification of α Cygni, and this still further complicates matters.

It will be seen that the question between the two classifications is a very sharp one. Is the difference between stars like δ Cephei and stars resembling the sun solely due to a temperature difference, as it is on Vogel's view, or does it in part represent, as I contend, a physical difference between the two classes, since on my view stars like δ Cephei consist of uncondensed swarms of meteorites of increasing temperature, while those like the sun are masses of vapour in which there are photospheres and relatively quiet atmospheres?

Since the work recently communicated to the Royal Society enables me to go still further forward, I propose to discuss in the present paper the points relating to the classification of stars of the δ Cephei class.

In Vogel's classification all stars are regarded as cooling bodies, while one of the chief points of mine is the distinction between stars which are getting hotter and those which are becoming cooler. Thus, while stars like δ Cephei and those like the sun are grouped together by Vogel in his Class IIa, they are in mine divided into two groups, Group III including δ Cephei and Group V the sun.

When I first suggested the new classification I fully recognised the difficulty of separating Groups III and V. Thus I wrote in 1888:—

"With our present knowledge, it is very difficult to separate those stars the grouping of which is determined by line absorption into Groups III and V, for the reason that so far, seeing that only one line of temperature, and that a descending one, has been considered, no efforts have been made to establish the necessary criteria."*

In the following year I gave the results of some visual observations of stellar spectra which seemed to justify the separation of the stars with line spectra into two groups, and to suggest the necessary criteria for distinguishing them.†

Soon after this a photographic investigation of stellar spectra was commenced at Kensington, and as a result of that work the conclusions at which I had arrived from a discussion of the eye observations were confirmed. The additional details shown by the photographs enabled me to extend the classification given in 1888.‡

* 'Roy. Soc. Proc.,' vol. 44, p. 27.

† 'Roy. Soc. Proc.,' vol. 45, p. 380.

‡ 'Phil. Trans.,' A, vol. 184, p. 125 (1893).

Stars resembling γ Cygni formed the sub-group IIIβ.

In November, 1895, I gave an account* of the spectra of five short period variable stars, δ Cephei, η Aquilæ, ζ Geminorum, T Vulpeculæ, and S Sagittæ, and pointed out that these belonged to the same sub-group as γ Cygni, which, however, is not a variable star; α Ursæ Minoris has also a spectrum which has since been recognised to be identical with that of γ Cygni and δ Cephei, while α Persei differs so slightly from them that it may also be classified with them.

These I now group together, and for convenience of reference I designate them the δ Cephei class.

Dr. Vogel's Classification.

Only two of the stars which have been mentioned as belonging to the δ Cephei class, namely, η Aquilæ and S(10) Sagittæ, were included in Vogel's spectroscopic *Durchmusterung*, published in 1883, and both are classed without further comment as stars of Class IIa.† This type of spectrum was thus defined: "Spectra with very numerous metallic lines, which are easily known by their intensity, especially in the yellow and green. The hydrogen lines are for the most part strong, but are never so broad as in the case of Class Ia. In some stars the lines of hydrogen are faint, and in these faint bands can be generally recognised in the less refrangible portion of the spectrum."

So far as Vogel's classification serves as a guide, then, all the stars of the δ Cephei class would be classed with the sun.

Dr. Scheiner has discussed one of the stars of the δ Cephei class, α Persei, in some detail.‡ Attention is specially drawn by him to the differences between the spectrum of α Persei and that of the sun.

In the following table I have brought together the lines of α Persei which Dr. Scheiner states to be more intense than in the sun, and have compared them with δ Cephei and α Cygni as photographed at Kensington. The remarks in the last column are those made by Dr. Scheiner with regard to the spectrum of α Persei.

* 'Roy. Soc. Proc.,' vol. 59, p. 103.

† 'Public. Astr. Obs. zu Potsdam,' vol. 3, p. 200.

‡ 'Public. Astr. Obs. zu Potsdam,' vol. 7, Part II, p. 329.

Special Lines in α Persei.

α Persei (Scheiner), λ Potsdam.	δ Cephei (Lockyer), λ Rowland. Maximum intensity = 10.	α Cygni (Lockyer), λ Rowland Maximum intensity = 10.	Remarks on α Persei (Scheiner).
4290·2	4290·7 (8)	4290·7 (4)	Stronger than in sun.
4306·3	4306·4 (5)	?	,, ,,
4310·1	..	..	No corresponding solar line.
4313·4	4313·3 (4)	4313·3	Stronger than in sun.
4321·4	?	4321·3 (2)	Much stronger than in sun.
4331·0	4331·1 (6)	4331·1 (2)	Stronger than in sun.
4344·7	4344·5 (5)	4344·5 (2)	,, ,,
4375·2	4375·0 (10)	4375·0 (2)	Much stronger than in sun.
4387·2	?	..	Stronger than in sun.
4391·4	4391·4 (5)	..	,, ,,
4394·4	4394·4 (6)	..	,, ,,
4400·0—4400·9	Broad line (8)	4400·0 (4)	,, ,,
4411·1	4411·0 (4)	..	No solar line.
4413·6	4413·6 (1)	..	,, ,,
4416·9	..	4417·4 (7)	,, ,,
4450·7	4451·1 (5)	4451·1 (4)	Stronger than in sun.
4461·7	4462·0 (5)	..	,, ,,
4464·7	4465·0 (2)	..	,, ,,
4468·7	4468·4 (6)	4468·4 (5)	,, ,,
4471·1	4471·1 (3)	4471·0 (2)	No solar line.
4473·1	4473·1 (3)	4473·1 (2)	Stronger than in sun.
4481·6	4481·3 (7)	4481·3 (9)	,, ,,
4488·6	4489·3 (5)	4489·3 (4)	,, ,,
4491·8	4492·0 (3)	4492·0 (4)	,, ,,
4501·5	4501·5 (7)	4501·5 (4)	Much stronger than in sun.
4508·5	4508·5 (5)	4508·5 (6)	,, ,,
4515·6	4515·6 (6)	4515·6 (6)	Stronger than in sun.
4520·6	4520·5 (3)	4520·5 (6)	,, ,,
4534·4	4534·3 (7)	4534·3 (6)	Much stronger than in sun.
4545·3	4545·3 (6)	4545·5 (1)	,, ,,
4549·9	4549·9 (7)	4549·9 (8)	Stronger than in sun.
4564·1	4564·1 (4)	4564·1 (5)	,, ,,
4572·0	4572·0 (5)	4572·0 (5)	,, ,,

Dr. Scheiner also remarks on a few of the special lines of α Ursæ Minoris, another member of the δ Cephei class. My own photographs show almost absolute identity with δ Cephei, so that a special discussion of this star would be superfluous.

It will be seen that the special lines of α Persei are nearly all present in δ Cephei and α Cygni, and that they are all either faint in, or absent from, the solar spectrum.

The spectrum of δ Cephei has been investigated by Belopolsky,* and he gives a table showing that it differs in many respects from that of the sun. Attention is specially drawn by him to some of the

* 'Ast. Nach.,' No. 3338, p. 19.

lines which are strongly marked in the spectrum of δ Cephei as compared with corresponding lines in the solar spectrum photographed with the same instrument. A discussion of these differences shows that the more special lines of δ Cephei, like those of α Persei, are very prominent in α Cygni.

In spite of these differences, Dr. Scheiner classes α Persei with stars like the sun, but regards it as a transition stage between α Cygni and the sun. He says: "From the general conclusions, the above list gives us quite a curious and important result. If one compares these lines with those in the spectrum of α Cygni, which is of special interest as an advanced spectrum of Class I*b*, one finds that, out of sixty lines in α Cygni, twenty-one occur in the list, and all of these in α Persei. The fact, therefore, remains that nearly half the lines which in the spectrum of α Persei show divergences when compared with the solar spectrum appear certainly in any case in the spectrum of α Cygni and determine its peculiarity.

"Now α Cygni belongs to Class I*b*, α Persei to Class II*a*, and the plausible conclusion appears to me, therefore, that α Persei had previously a spectrum similar to that of α Cygni, and that in this case we have the missing connexion between I*b* to II*a*." *

The spectrum of α Tauri, which, as I shall show, must be regarded as a condensing swarm, closely resembles that of the sun; so that Dr. Scheiner's evidence would equally place α Persei intermediate between α Tauri and α Cygni.

Difficulties connected with Vogel's Classification.

The close association of stars like δ Cephei with those like α Cygni makes it here important to discuss the place of α Cygni in Vogel's classification. With regard to this star Dr. Scheiner writes: "The spectrum of α Cygni, in spite of the large number of its lines, has no resemblance with that of the sun. While it is possible to identify most of the lines with solar lines in respect of their position, yet the total lack of agreement as to intensity of the lines makes many of these identifications worthless." †

Dr. Scheiner has classified α Cygni in Vogel's Class I*b*, which was thus defined in Vogel's original classification: "Spectra in which the metallic lines are few in number, and very faint or entirely imperceptible, and in which the hydrogen lines are lacking."

In view of the photographic results obtained at Potsdam, the last clause in this definition was corrected in 1888, so that it reads: "and the strong hydrogen lines of Type I*a* are lacking." ‡ This has again been modified by Dr. Scheiner, and the characteristics of

* 'Potsdam Observations,' vol. 7, Part II, p. 331.

† Scheiner's 'Astronomical Spectroscopy' (Frost's translation), p. 247.

‡ 'Ast. Nach.,' vol. 119, p. 97.

Type I*b* are stated as "spectra in which the hydrogen lines and the few metallic lines all appear to be of equal breadth and of sharp definition."* It is on the ground of this greatly modified definition that α Cygni is included with stars like Rigel in Class I*b*.

Dr. Vogel, however, is not prepared to accept Dr. Scheiner's amended definition of Class I*b*. He writes: "However justifiable it may be to regard the peculiarly sharp spectral lines of the stars above mentioned and a few others of the same kind as worthy of special consideration, the adoption of this proposal would make it necessary to separate a number of stars (including those of Orion) whose relationship is placed beyond all question by the investigations I have referred to, and to place them with α Cygni, which has a materially different spectrum."†

In the same paper Dr. Vogel brings forward a new definition of his Class I*b* in the following terms: "Spectra in which, besides the still dominant hydrogen lines, the lines of cleveite gas appear, and above all the lines λ 4026, λ 4472, λ 5016, and λ 5876(D_3). The lines of calcium, magnesium, sodium, and iron are also more or less numerous in spectra of this subdivision."

This new definition excludes α Cygni from Class I*b* in Dr. Vogel's opinion, and he places this star in Class I*a* 3 of his extended classification of spectra of the first class. This sub-class is thus defined: "Spectra in which the calcium line λ 3934 has nearly the same intensity as the hydrogen lines. In occasional instances it is still sharply defined at the edges, or it may be broader and more intense than the hydrogen lines, and very diffuse, forming with the hydrogen line $H\epsilon$(λ 3970), which is greatly intensified and broadened by the calcium line λ 3969, a conspicuous pair.

"In the spectra of this division the lines of the cleveite gas cannot be recognised; on the other hand, numerous strong lines of different metals, particularly lines of iron, are always present. The lines of hydrogen are still always dominant. $H\delta$ is plainly apparent among the other lines, and the group G is less conspicuous than $H\gamma$. This subdivision forms the direct connecting link with the spectral class II, in which the hydrogen lines no longer play a prominent part in comparison with the lines of other metals."‡

According to this definition, α Cygni is classed with Procyon, a star which in the main resembles the sun, and this notwithstanding Scheiner's remark that the spectrum of α Cygni bears no resemblance to that of the sun.

It is clear, then, that α Cygni cannot be classified satisfactorily on the supposition that all stars are cooling.

* Scheiner's 'Astronomical Spectroscopy' (Frost's translation), p. 245.

† 'Astrophysical Journal' (1895), vol. 2, p. 343.

‡ 'Astrophysical Journal' (1895), vol. 2, p. 344.

Reference to the Old Evidence of Two Series.

In previous communications to the Royal Society I have stated the evidence which shows that in stars of Group II, such as α Orionis, the occurrence of radiating carbon vapour is an indication that these stars, like comets, consist of uncondensed swarms of meteorites. Since the temperature of a condensing swarm of meteorites must be increasing, in accordance with thermodynamical principles, stars like α Orionis must be placed on the ascending arm of the temperature curve. The photographs show that the spectrum of stars like α Tauri is almost identical with that of α Orionis so far as the lines are concerned, and since one of the flutings in the red in the spectrum of α Orionis also appears in α Tauri, this star must also be regarded as one of increasing temperature.

The discussion of the Kensington photographs led me to place γ Cygni next to α Tauri in the series of stars with increasing temperature,* and we now know that δ Cephei must be classed with this star. I pointed out that the spectrum of γ Cygni "has much in common with that of α Tauri, but there is less continuous absorption, and many of the lines of α Tauri thin out. The next step to α Cygni is rather a long one, but it seems very probable that if more photographs were available intermediate spectra would be found. It will be seen, however, that in α Cygni the hydrogen lines are intensified as compared with γ Cygni, and that all the important lines of α Cygni agree in position with prominent lines in γ Cygni. . . . . . In passing to Rigel the more important lines of α Cygni are retained, and a few new lines make their appearance."

My argument was, then, that with an increase of temperature a star like α Tauri would develop into one like δ Cephei, which, with further increase, would pass through successive stages represented by α Cygni, Rigel, and Bellatrix. To justify this it is accordingly necessary to show greater reason for associating δ Cephei with α Tauri than with a star like the sun, which we know on other grounds to be cooling.

From the great similarity of the line spectra of α Tauri and the sun, it is clear that the argument will not entirely depend upon the identity of lines in the spectra of α Tauri and δ Cephei, but upon general and specific differences between δ Cephei and the sun.

Evidence from Enhanced Lines.

In a recent communication to the Royal Society,† I have shown that the investigation of the lines enhanced in the spark spectra of

* 'Phil. Trans.' (1893), A, vol. 184, p. 708.

† 'Roy. Soc. Proc.,' vol. 61, p. 181.

metals has enabled me to apply new criteria in the classification of stellar spectra.

A study of these lines shows at once that δ Cephei is hotter than either α Tauri or the sun, and that the difference between its spectrum and that of α Tauri or the sun is certainly in part due to this difference of temperature of the absorbing vapours. The lines which are stronger in δ Cephei than in the sun include many of those which have been found to be enhanced in the spark spectra of metals, so that they are no longer to be regarded as unknown lines. Similarly, many of the lines of α Cygni for which no origins could previously be assigned have been shown to be lines of common metals under conditions of high temperature. Still, the mere presence of the enhanced lines in a star spectrum affords us no criterion as to whether the temperature of a star is increasing or decreasing. But I have also shown that if we take the relative intensities of the enhanced lines and the arc lines as an indication of stellar temperatures, and in this way bring together a sufficient number of stars of about the same temperature as γ Cygni or δ Cephei, such spectra may be divided into two well-marked groups, of which γ Cygni and Castor may be taken as types. The chief generic differences between the two groups of stars at the temperature of δ Cephei were thus summarised in the paper to which reference has been made :—

δ Cephei.	Castor.
(1) Considerable absorption in ultra-violet.	(1) Very little continuous absorption in ultra-violet.
(2) Hydrogen lines relatively thin.	(2) Hydrogen lines relatively very thick.
(3) Metallic lines of moderate intensity.	(3) Metallic lines relatively feeble.

I further showed that these differences are simply and sufficiently explained on the supposition that stars like γ Cygni and δ Cephei are uncondensed swarms of meteorites, while those like Castor, which have about the same mean temperature, are stars approaching the condition of the sun in which photospheres and relatively quiescent atmospheres have formed. The foregoing considerations indicate that there are three chief periods in the history of a star during its stages of luminosity :—

(1) A period during which it exists as an uncondensed swarm, when the "atmosphere" is disturbed by meteoritic bombardment from without.

At this stage the atmosphere is a mass of heterogeneous vapour at various temperatures and moving with different velocities in different regions.

(2) A period of complete vaporisation during which the atmosphere is quiescent, bombardment having ceased, and the radiation being too great to permit condensation in the atmosphere.

(3) A period of cooling during which the atmosphere is disturbed by the fall of condensation products from the outer parts of the atmosphere on to the photosphere.

Evidence that we are not dealing with Composite Spectra.

Many of the lines in the spectra of stars of the δ Cephei class coincide with prominent lines in the spectrum of α Cygni, but it is true that many also coincide with lines in the spectra of stars like α Orionis and Arcturus, which closely resemble the solar spectrum. It seemed possible, therefore, that we might be dealing with the integrated spectra of two stars in close proximity, one having lines resembling those of α Orionis or Arcturus, and the other those of α Cygni. The spectra of all the stars of this sub-group have accordingly been very carefully investigated from this point of view. Enlarged glass positives of α Cygni and Arcturus on exactly the same scale have been superposed, and the integrated spectra photographed. When this integrated spectrum is compared with γ Cygni or δ Cephei, there is a considerable similarity, but the relative intensities of the various lines and the general appearance of certain parts of the spectrum, especially about G, are quite different. Again, if there were two bright bodies physically connected in such a star as γ Cygni there must be a revolution and a consequent doubling of the common lines, unless the plane of movement were perpendicular to the line of sight. No signs of such doubling, however, have been detected in any of the eight stars of the sub-group which have so far been recognised, and it is quite improbable that the plane of revolution would be at right angles to the line of sight in every case, and still more so that the two components would have identical spectra in each of the eight systems.

Spectra of the δ Cephei type must, therefore, be taken to represent a particular stage in the orderly development of cosmical bodies.

Evidence from Variability.

Further evidence in favour of placing stars like δ Cephei and γ Cygni on the ascending arm of the temperature curve is afforded by the fact that stars of this class present a special form of variability. This variability is similar in kind, but different in degree, to that associated with stars of Group II, such as Mira. The following table shows that the amount of variation is very much less than that in variables of the Mira type:—

Name.	Period.		Interval from min. to max.		Variation.	Remarks.
	d.	h.	d.	h.		
δ Cephei	5	9	1	15	3·7—4·9	Very regular.
ζ Geminorum	10	4	5	0	3·7—4·5	Period slowly lengthening.
η Aquilæ	7	4	2	9	3·5—4·7	Slightly irregular.
S(10) Sagittæ	8	9	3	10	5·6—6·4	
T Vulpeculæ	4	10	1	7	5·5—6·5	
Mira	331	0	..		(1·7—5·0) — (8·7—9·5)	

It will be seen that the luminosity at maximum is from about two (0·8 magnitude) to three times (1·2 magnitudes) greater than at minimum, while the forms of most of the light curves resemble the majority of those of the Mira class in the relatively steep ascent to maximum. A constitution more or less similar to that of the Mira class is therefore indicated.

I have already shown that in such variables as Mira the presence of bright carbon flutings indicates a meteoritic structure.* Here the variation has a much longer period than in δ Cephei, but it is only necessary to suppose that δ Cephei is more condensed, so that revolving swarms of short period will be alone effective in producing collisions at periastron, as I pointed out in 1889.†

A recent discussion of all the available observations of η Aquilæ by Dr. William J. S. Lockyer‡ has shown that the light curve of this variable can be best explained on the supposition of three meteor swarms moving around their centre of gravity. In this way not only is the general form of the light curve satisfied, but the smaller irregularities discovered by the author are also easily accounted for.

Hence, by placing stars of the δ Cephei class on the ascending arm of the temperature curve, the variability of certain members of the group finds a ready explanation. I am not aware of any satisfactory explanation of the δ Cephei type of variability in which a constitution resembling that of the sun is assumed, and to my mind such a variation in a star constituted like the sun is impossible.

* 'Roy. Soc. Proc.' (1887), vol. 43, p. 130.

† 'Roy. Soc. Proc.,' vol. 46, p. 420.

‡ 'Resultate aus den Beobachtungen des veränderlichen Sternes η Aquilæ' (Inaugural-Dissertation, Göttingen, 1897).

General Conclusions.

The final result of the discussion of the spectra of stars of the δ Cephei class is to show that they must be placed on the ascending arm of the temperature curve, at a stage higher than stars like α Tauri, in which the mean temperature is not very different from that of the sun. Stars of equal temperature on the descending side of the curve, of which Castor may be taken as a type, show precisely the same lines, the enhanced and cool lines having the same relative intensities, but with inverted intensities of the hydrogen and metallic lines, and with somewhat less continuous absorption in the ultra-violet. The difference between stars like δ Cephei and those of the sun is therefore partly due to a difference of temperature and partly due to a difference of physical condition such as is demanded by the meteoritic hypothesis. This result enables us to understand why some members of the δ Cephei class should show such a very special kind of variability.

α Cygni also finds a natural place on the ascending arm of the temperature curve, at a stage higher than δ Cephei, and all the difficulties met with in attempting to classify it on Vogel's view of decreasing temperature alone are removed.

"On Lunar and Solar Periodicities of Earthquakes." By ARTHUR SCHUSTER, F.R.S. Received May 18,—Read June 17, 1897.

1. In a paper recently communicated to the Royal Society "On Lunar Periodicity in Earthquake Frequency," Mr. C. G. Knott gave some results, from which he argued that a real connexion between tidal effects and earthquakes probably existed. These results are based on a method which has frequently been employed. The records of earthquakes are grouped together and expressed by means of a Fourier series, and conclusions are based on the greater or smaller values of the coefficients of this series. In order to decide what value is to be attached to such investigations, it seems necessary in the first instance to discuss what would be the order of magnitude of the coefficients, on the supposition that the events have happened perfectly at random without any connecting law. It is the object of this paper to solve this question, and to apply the solution to the periodicities which are supposed to exist in the frequency of earthquakes.

2. If it is required to investigate a possible period of p intervals of time in a series of members, t_1, t_2, t_3, &c., it is usual to arrange the numbers according to the following scheme, where t_1' stands for t_{p+1}, t_1'' for t_{2p+1}, &c. :—